Tools for simulations

Event Generators at sqrt(s)=115 GeV

Opening the discussion …

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Physics at A Fixed Target ExpeRiment (AFTER) using the LHC beams
3-13 Febuary 2013 ECT Trento

Outline

- Event generators physics
- Why to use them?
- Questions raised by AFTER
- Non-exhaustive overview of event generators on the market
- Which one to do what?
- Conclusions

Event generators physics

<u>Goal (dream ?) :</u>

- to reproduce entirely an event : particles in final state with all properties
- with all steps and physics features (soft, hard, interplay between the two, hydro?, all observables, …)
- Should give access to exclusive observables
- Different from a calculation/computation usually inclusive and for one observable (for example pT spectrum in pp-> J/Ψ +X)

<u>Strategy :</u>

- Initial state
- Elementary interactions : soft, hard, both?
- Radiation
- Remnants
- Multiple interactions
- Underlying events
- Particle production (string picture?)

Why to use them?

➢ Simulate events for detector/analysis purpose

- Generate events for corrections
- Test an analysis process on MC data prior to real data
- Test your comprehension of your detector (MC = Event generation + Geant simulation of detector)

} For this, do you need a sophisticated baseline model of your event generator ?

➢ Model Comparison

- If you look at pure inclusive observables, maybe there is a model on the market that will be more adapted
- If you start looking at exclusive staff : particle correlations, soft vs. hard, …
  Event generators trying to reproduce all aspects of the event could be of interest

Questions raised by AFTER

- Fixed target → Various possible targets with two beams (p or Pb)
  → Various systems : pp, pA, AA
  → $-4,8 < Y\_cms < 1$

Do you want one single event generator for all systems?

- Energies : sqrt(s) = 72-115 GeV → Between SPS and RHIC

You need an event generator that gives consistent simulations at SPS and RHIC.

Do you need all new features developed for Tevatron and LHC?

- Observables : photons, jets, Quarkonia and open heavy flavors, identified soft particles
  → Various observables either soft and hard

Do you want one single event generator for all?

Non-exhaustive Overview of event generators on the market

pp event generators

- PYTHIA
- Herwig

Based on pQCD approach : the hard interaction is the basis of the framework

- EPOS
- Sherpa

Based on Gribov-Regge approach, multiple interactions are the basis of the framework

Specialization, complement

- ALPGEN : include detailed multiple hard processes
- Jimmy
- Cascade : hard process with parton evolution

pp, pA, AA

- Hijing — Based on PYTHIA, with emphasize on minijet, include nuclear shadowing
- AMPT — Hijing for initial condition, add final state scattering to generate elliptic flow
- EPOS — Picture of Elementary parton-parton interactions viewed as color flux tube extended to all system, with shadowing and hydro evolution
- Hydjet++ — Hydro evolution (only AA?)

https://karman.physics.purdue.edu/OSCAR-old/models/list.html

http://en.wikipedia.org/wiki/Event_generator

A completely biased selection

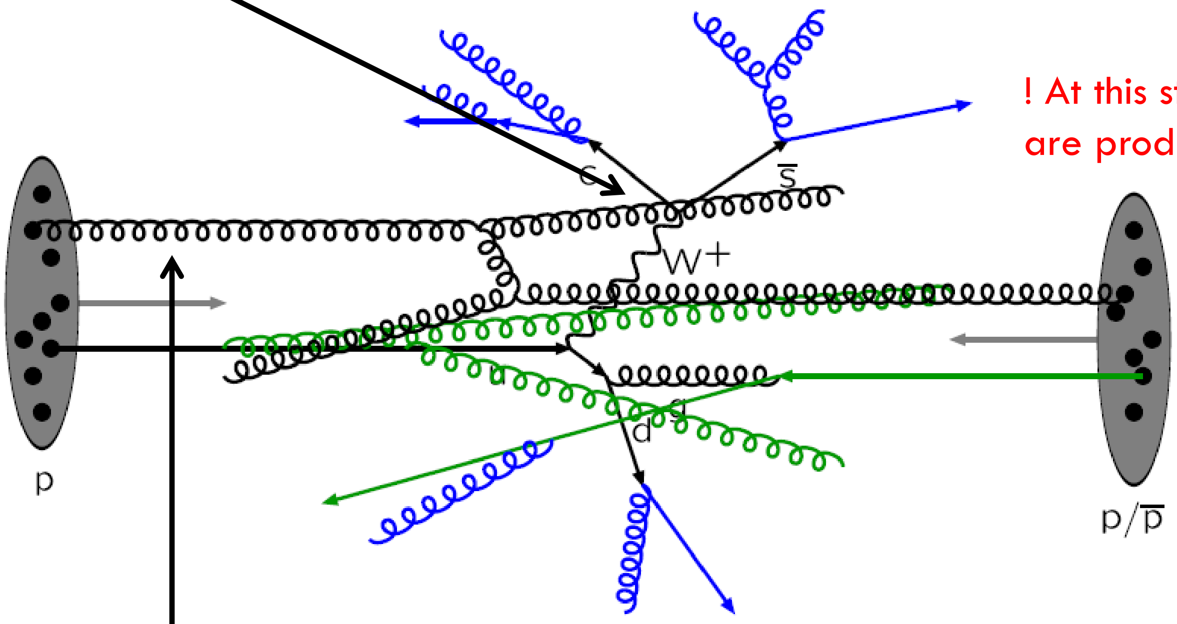
In the following :

- PYTHIA
- EPOS
- A bit of Hijing and AMPT

PYTHIA Physics : ref 6.4 Manual

http://arxiv.org/abs/hep-ph/0603175

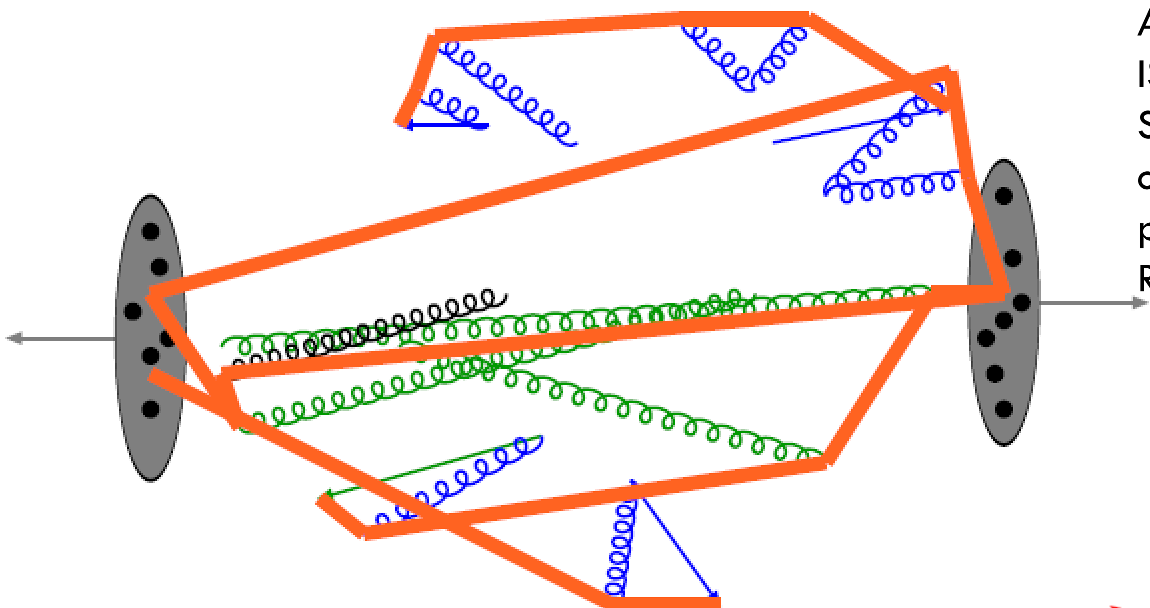
1) The first hard interaction is the first step of event machinery :
Computed in pQDC framework with factorization, possibility to select hard process : charm, bottom, jets, photon -> can tune this step



! At this step only partons are produced

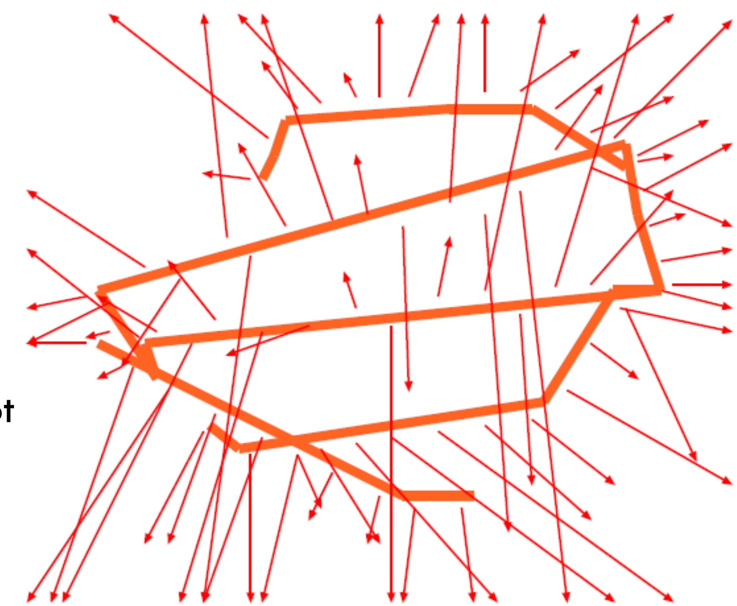
2) MPI (Multiple Parton Interaction) : other processes (soft or hard) can happen in parallel:
PYTHIA model : the first hard interaction is particular, other are reconstructed afterward, ordered in hardness, in PYTHIA 6, only g,u,d,s available in other interaction,
In PYTHIA 8 : second hard can include charm and bottom

PYTHIA Physics : ref 6.4 Manual



All produced partons (in hard process, ISR/FSR (Initial State Radiation/Final State Radiation), MPI, remnants, …) are connected via strings : the LUND procedure,

Resonance let out of the machinery

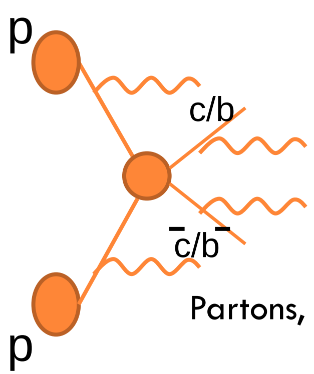


Formed strings decay into hadrons
(fragmentation via qqbar pairs, pop-corn to produce baryons)
qqbar : u,d,s,c (c is suppressed but available), heavier not implemented

How to produce heavy state in PYTHIA?

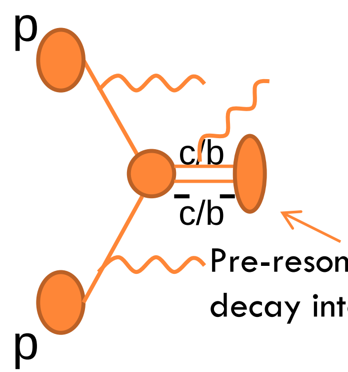
❖ In the 2->2 hard sub-process : Hard production

1) Open heavy flavor



Partons, connected to strings

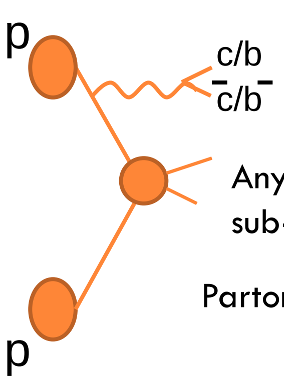
2) Resonnance production



To be checked : can a pre-resonnan state decay into D meson?

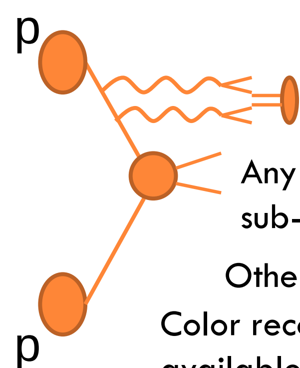
Pre-resonant state (NRQCD): decay into J/Psi or Upsilon

❖ Gluon splitting (g->QQbar, gluon originated from ISR/FSR)



Any hard 2->2 sub-process (gg->gg for example)

Partons, connected to strings



$c\bar{c}$ cluster decay into J/Ψ

Any hard 2->2 sub-process (gg->gg for example)

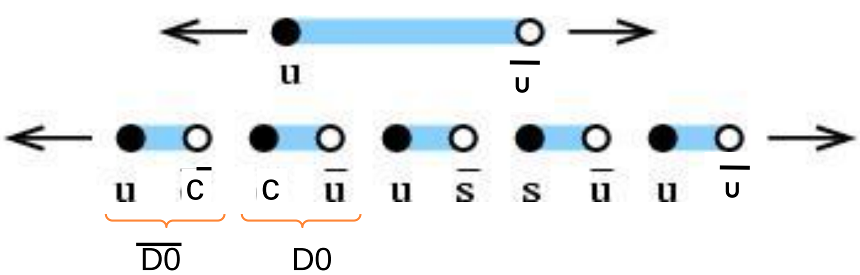
Other c/b connected to strings

Color reconnection make this contribution available with only one g->Qqbar : artificial enhancement of this contribution in PYTHIA6.4

(N.B : Cluster : small peace of string : decay directly into hadrons)

How to produce heavy state in PYTHIA?

❖ String fragmentation



An event can still produce J/Psi and D mesons via string fragmentation

cc pair production suppressed as compare to u, d, s, but available : limit at high energy?

Higher state not available

How to tag the origin of heavy state?

- easy for resonance : direct information via the mother!
- Due to final string procedure : difficult for open charm and open beauty : they all finally comes from strings
- For open charm and open beauty is there really a physical sense for differentiation?

PYTHIA 8

http://arxiv.org/pdf/0710.3820.pdf
http://home.thep.lu.se/~torbjorn/pythia8/worksheet8160.pdf

In C++

The actual developed code (PYTHIA 6 maintained, but not developed)

MPI scenario : possibility of charm and bottom in the hard process of second hard interaction : user can play with this!!!

PYTHIA +

A bit of everything, even if the physics model is not perfect
Extensively used, tuned, debugged, interfaced to other codes

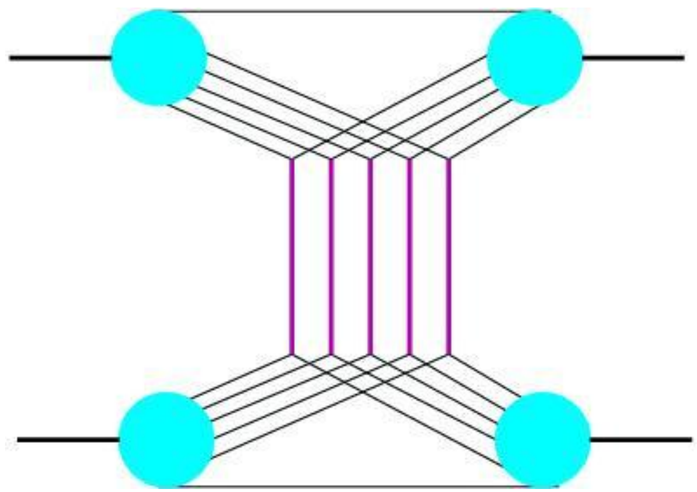
PYTHIA -

Only pp

A bit of everything, even if the physics model is not perfect (eg. quarkonia)

Not PYTHIA, but PYTHIAS : many many tunes, one single framework?

EPOS for pp



Parton-based Gribov-Regge Theory

Mixed approach between parton model and Gribov-Regge

Energy shared between all elementary interactions

Same formalism for cross section computation and particle production

Elementary interaction = $\sum$ soft + Semi-hard

soft: parameterized

hard: parton model

semi-hard: soft pre-evolution before the hard part

EPOS
theoretical framework

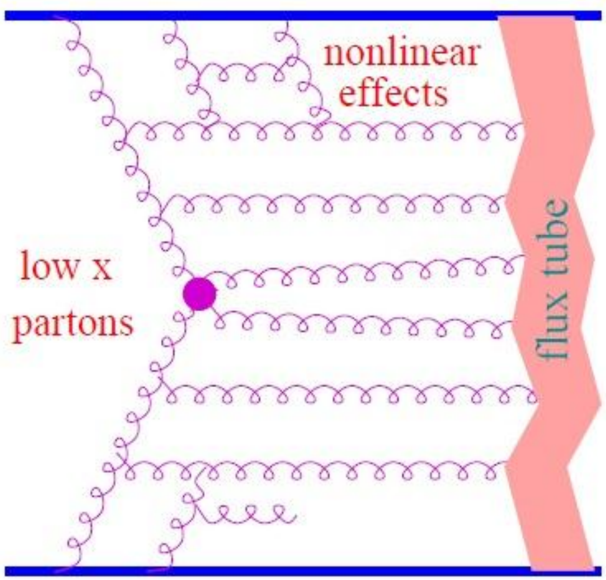
Energy conserving quantum mechanical multiple scattering approach based on :

- Partons, parton ladders, strings
- Off-shell remnants
- Splitting of parton ladder

S. Ostapchenko, T. Pierog, K. Werner, H.J. Drescher, M. Haldik Phys. Rep. 350 (2001)

EPOS for pp

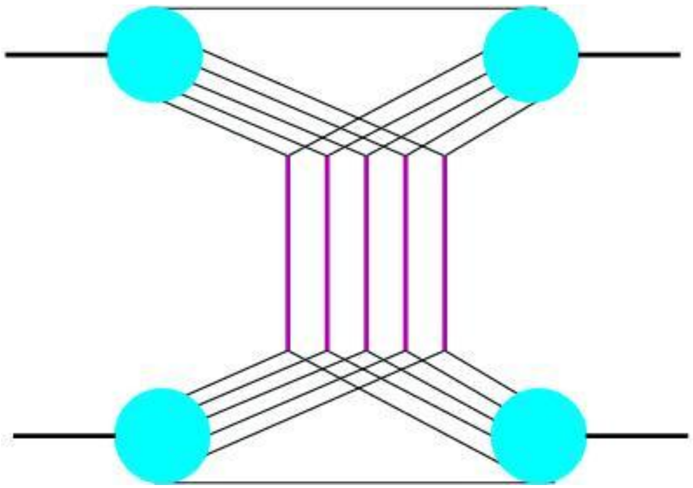
Elementary scattering - flux tube

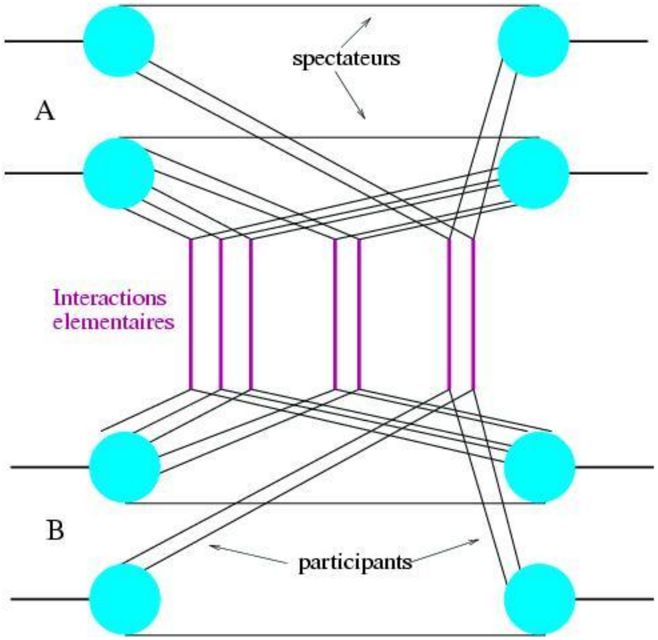


- Parton evolutions from the projectile and the target side towards the center (small x)
- Evolution is governed by an evolution equation, in the simplest case according to DGLAP.
- **Parton ladder may be considered as a quasi-longitudinal color field, a so-called flux tube, conveniently treated as a relativistic string.**
- **Intermediate gluons are treated as kink singularities in the language of relativistic strings, providing a transversely moving portion of the object.**
- flux tubes decay via the production of quark-antiquark pairs, creating in this way fragments – which are identified with hadrons

EPOS for heavy ion

Same framework extended





pp → AB

EPOS for heavy ion

EPOS 2 : with hydro

In heavy ion collision / or very high energy pp collision :

- The usual procedure has to be modified, since the density of strings will be so high that they cannot possibly decay independently
- Some string pieces will constitute bulk matter, which expands as a fluid, others show up as jets

Event by event hydro-evolution

Initial condition given by flux tube picture

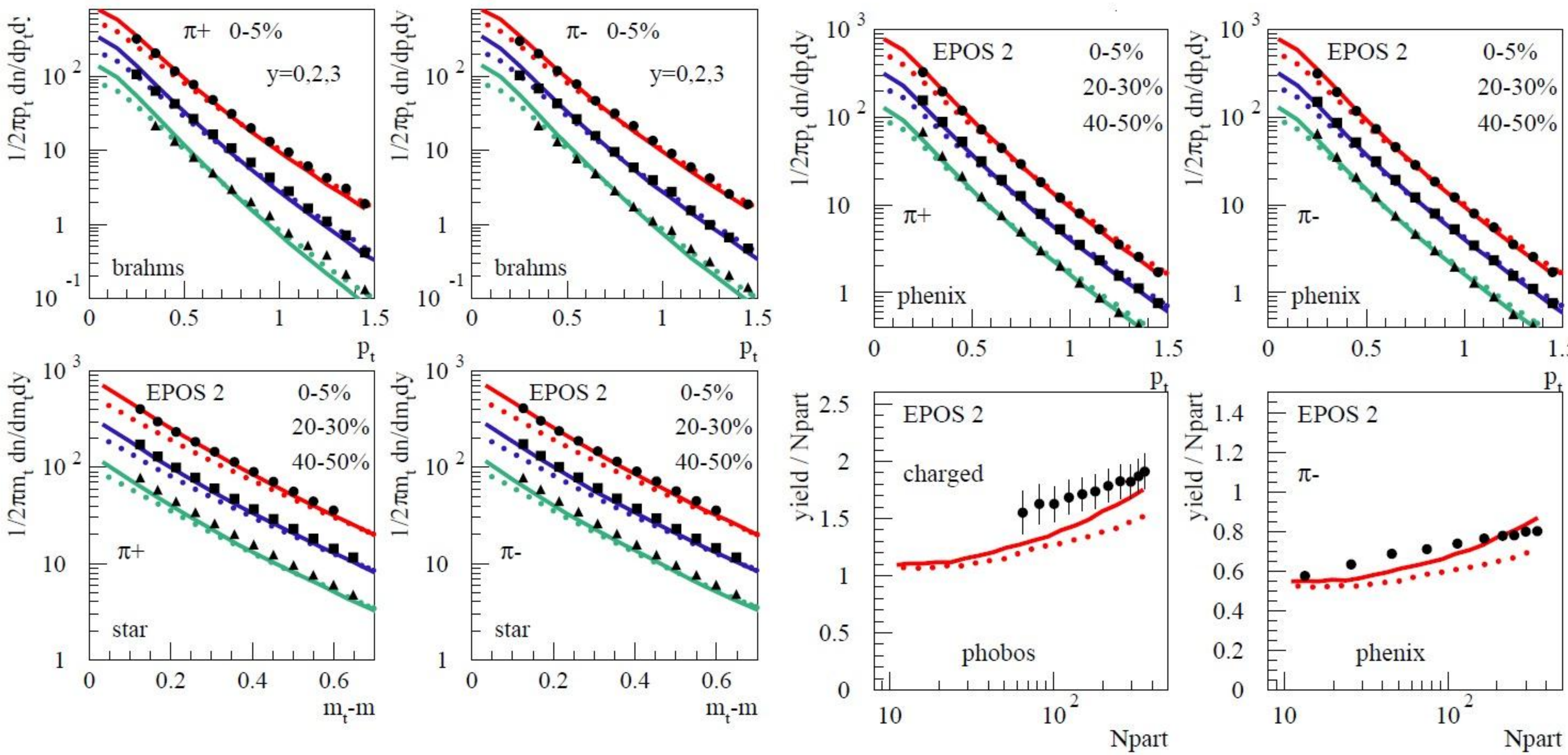
⚠ **EPOS 2, not yet public, should be available by 2013!**

"Event-by-Event Simulation of the Three-Dimensional Hydrodynamic Evolution from Flux Tube Initial Conditions in Ultrarelativistic Heavy Ion Collisions" arXiv: 1004.0805

"Jets, Bulk Matter, and their Interaction in Heavy Ion Collisions at Several TeV." arXiv : 1203.5704

EPOS for heavy ion

Pions at RHIC : AuAu, sqrt(s)=200 GeV



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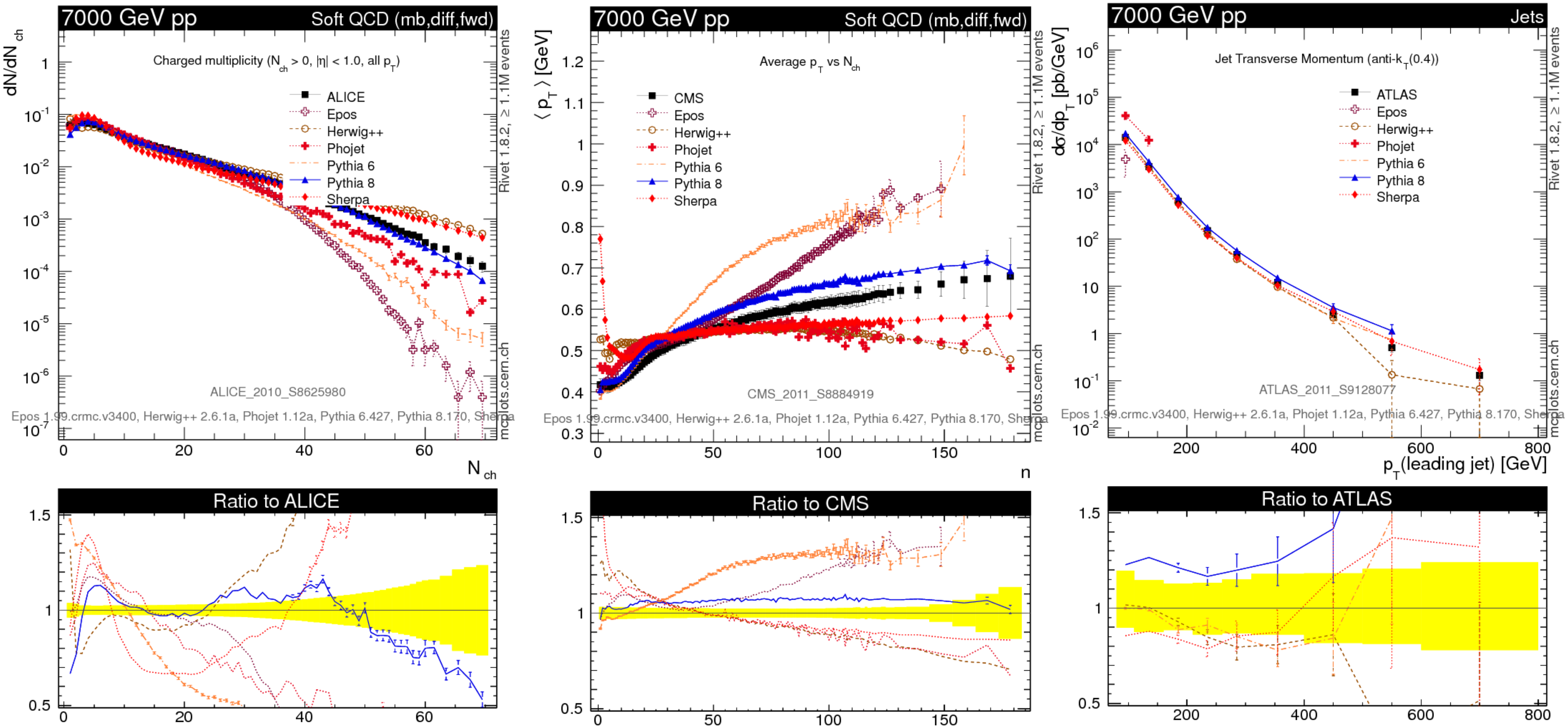
Comparison plots for pp data

http://mcplots-dev.cern.ch/

MC versions and tuned used!

Online “repository of MC plots comparing High Energy Physics event generators to a wide variety of available experimental data, for tuning and reference purposes.”



HIJING

« HIJING 1.0: A Monte Carlo program for parton and particle production in high-energy hadronic and nuclear collisions. »
nucl-th/9502021,LBL-34246. Comput.Phys.Commun. 83 (1994) 307 e-Print: nucl-th/9502021

« Hadron production in p+p, p+Pb, and Pb+Pb collisions with the HIJING 2.0 model at energies available at the CERN Large Hadron Collider »
Published in Phys.Rev. C83 (2011) 014915 e-Print: arXiv:1008.1841 [hep-ph]

Main features of HIJING :

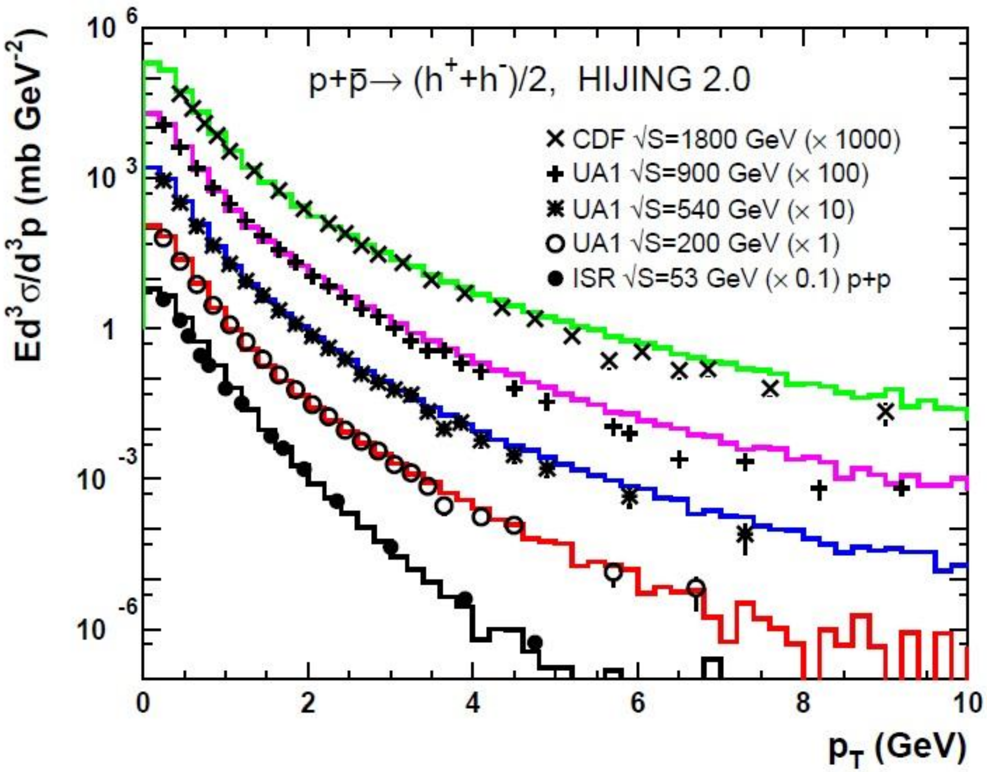
- Multiple mini-jet production according to an eikonal formalism for each nucleon-nucleon collision at given impact parameter b.
  Kinematic of each pair of jets + their ISR/FSR done by PYTHIA model

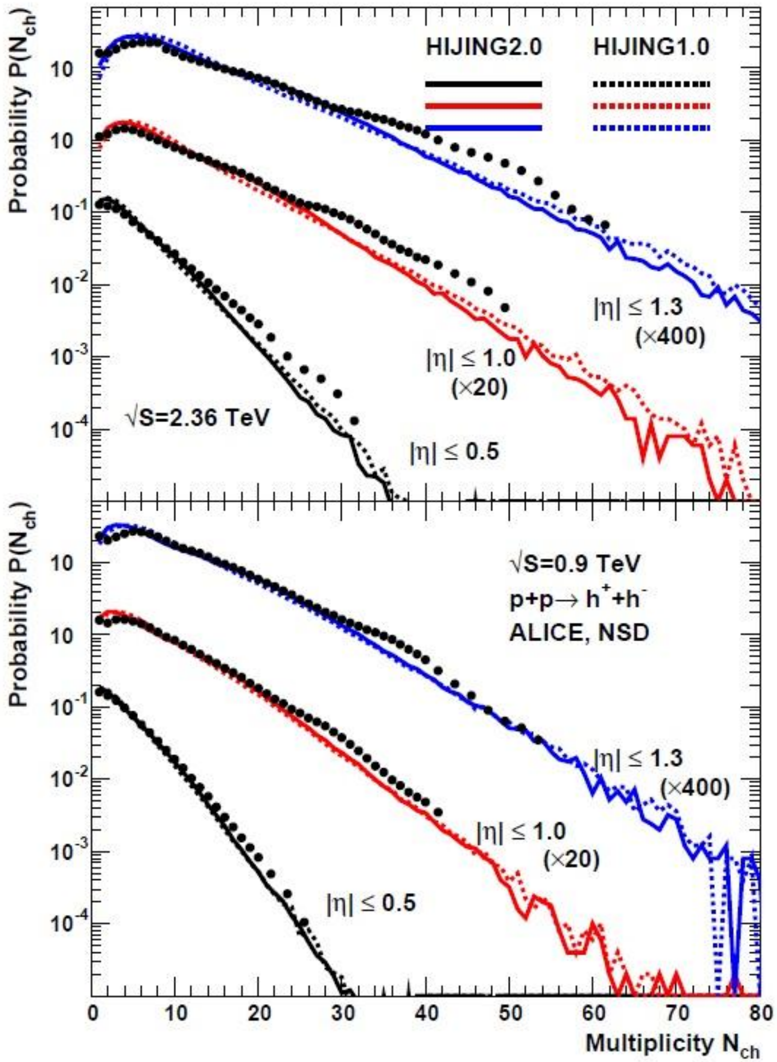
- Events without jet production (with pT>p0) and underlying soft parton interaction in event with jet production are modeled by excitation of quark-diquark strings with gluon kinks (FRITIOF and DPM model) + multiple low-pT exchange

- Nuclear modification of the PDF inside the nuclei with a set of impact-parameter dependent parton distribution functions, Version2 with more modern parameterized PDF

- Simple model for jet-quenching (jet-medium interaction in AA)

HIJING





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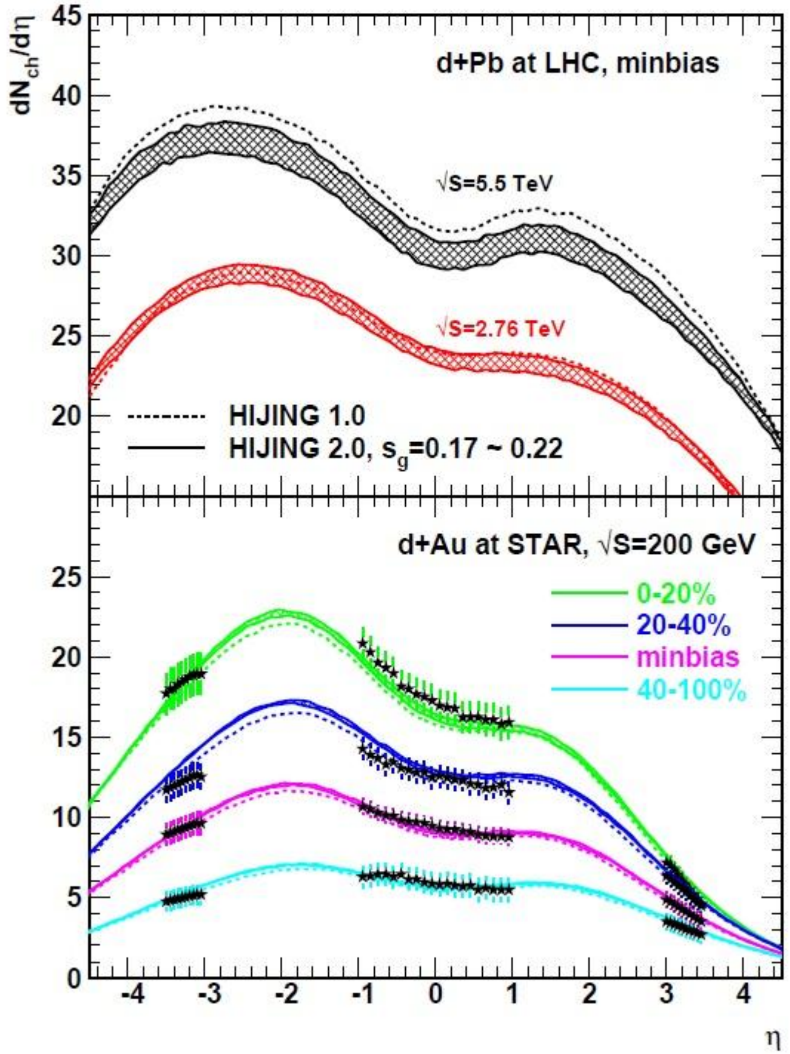

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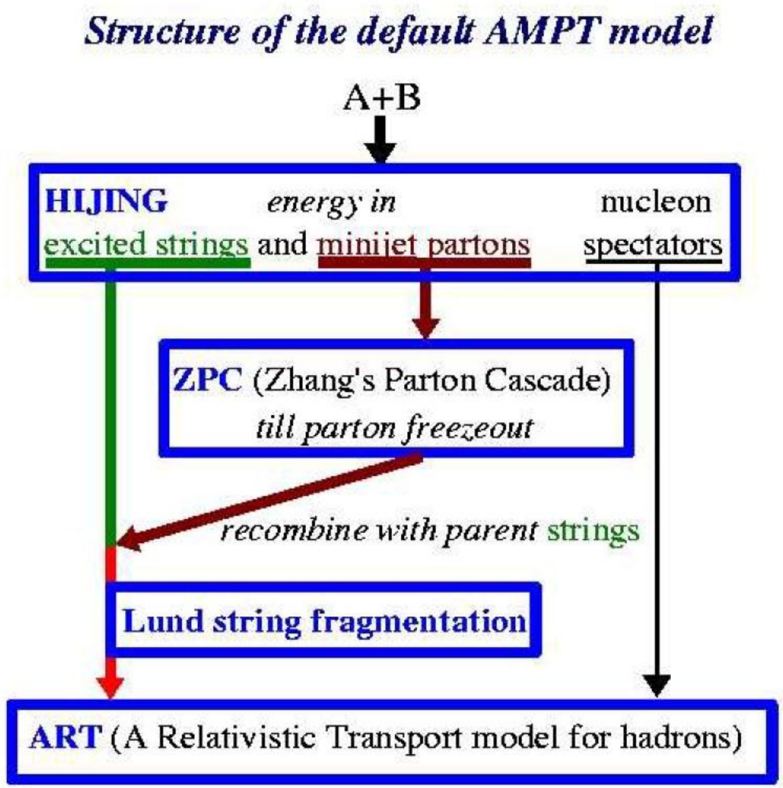
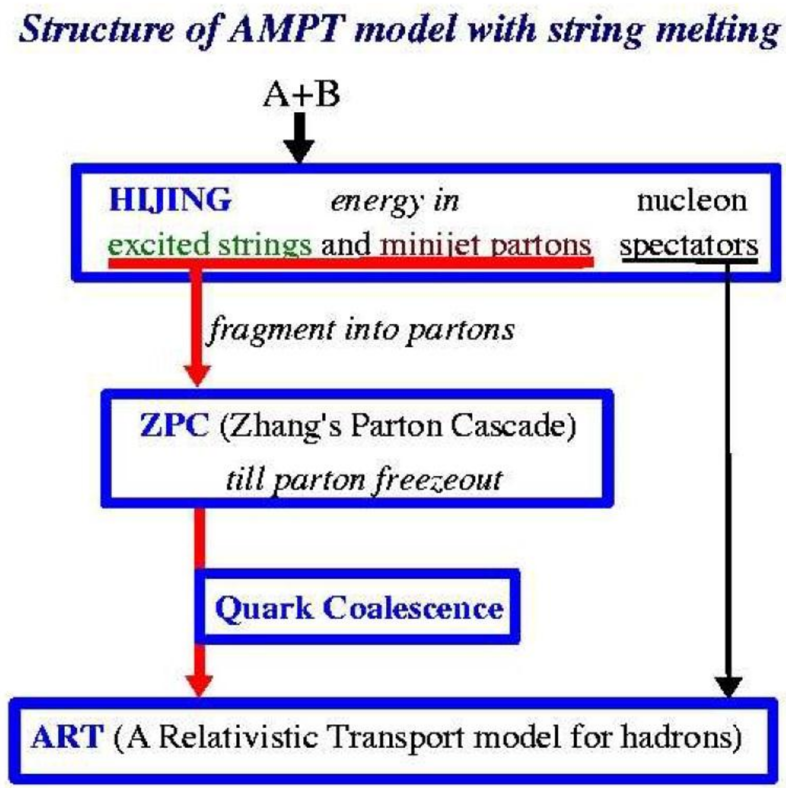
AMPT

« Pb-Pb collisions at $\sqrt{s_{NN}}=2.76$ TeV in a multiphase transport model » arXiv 1101.2231

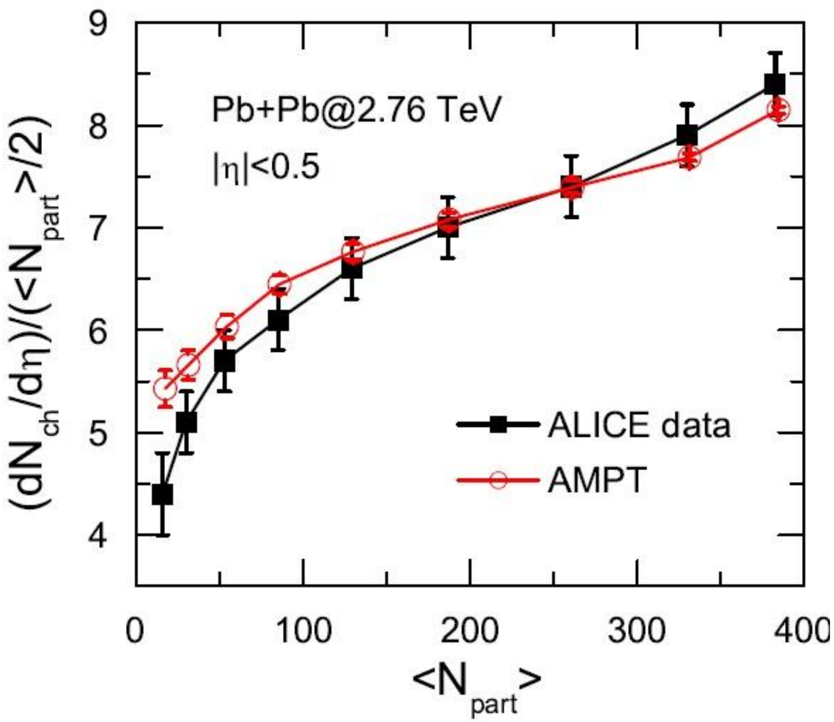
« A Multi-phase transport model for relativistic heavy ion collisions. » Published in Phys.Rev. C72 (2005) 064901 e-Print: nucl-th/0411110

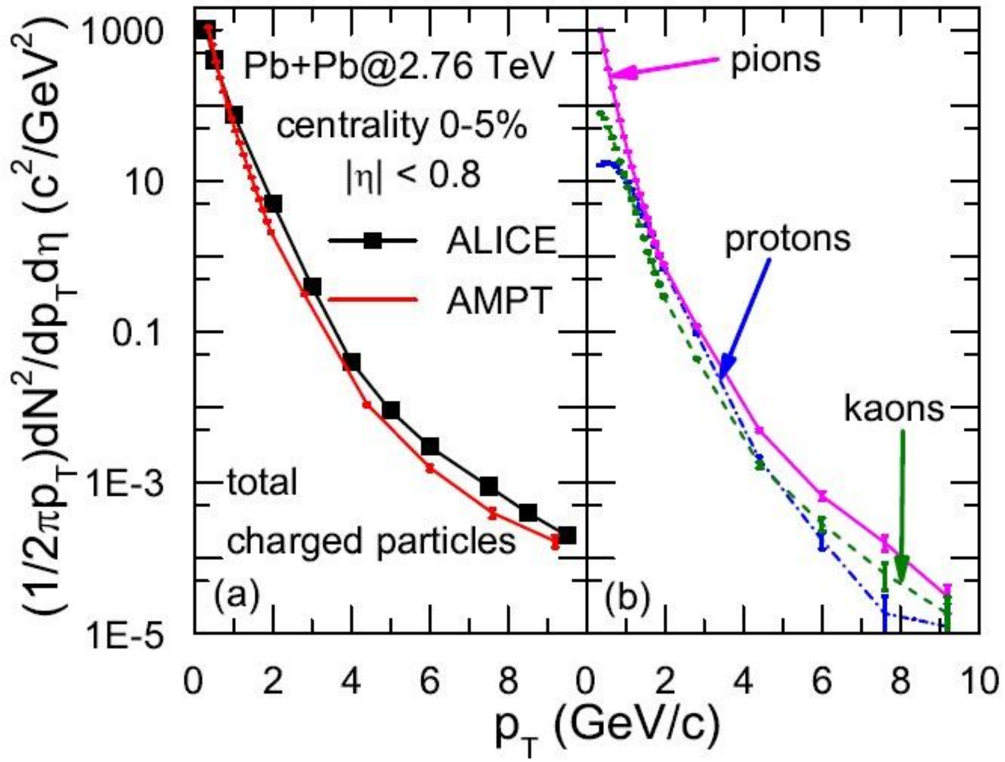
An hybrid model, 2 versions





AMPT





« Pb-Pb collisions at $\sqrt{s_{NN}}=2.76$ TeV in a multiphase transport model » arXiv 1101.2231

Which one to do what?

model	EPOS	PYTHIA	Hijing	AMPT
systems	pp, pA, AA	pp	pp, pA, AA	pp?, pA, AA
Baseline	Multiple Interaction	Hard process	PYTHIA 5,3? + minijet + nuclear structure	HIJING + transport model (ZPC parton cascade)
MPI	Parton-based Gribov-Regge Theory	Reconstructed after the hard process. Interaction ordered in hardness. In the new model : color reconnection	modeled by exitation of quark-diquark strings with gluon links + multiple low-pT exchange →	
Hard process	Hard and semi-hard ladder with soft pre-evolution u, d, s, g, gamma, c in progress	Based on inclusive cross section → Almost everything, if not in the code, can couple with extra code	PYTHIA 5,3 →	
Quarkonia	In progress	Yes : model to be taken with caution.	?	?

Which one to do what?

model	EPOS	PYTHIA	Hijing	AMPT
Initial and Final state radiation	Iterative procedure from partons in hadrons to 2->2 process	A posteriori reconstruction Available for MPI in the new model (6.4)	→ PYTHIA 5,3	→
Collectivity	Yes, available with string density, eg. for all systems if energy density high enough. Event by event hydro in EPOS2	No	Simple model for jet-quenching (jet-medium interaction in AA)	transport model
Hadronization	String model with area law, diquark for baryon production	String model with fragmentation function, popcorn for baryon production	→ PYTHIA 5,3	→
Remnant	Yes Off-shell treatment	Yes	→ PYTHIA 5,3	→
Connection between hard processes and MPI	Total by construction : several ladders soft or hard, energy conservation and color connection	With color reconnection (6,4), final state effect	modeled by excitation of quark-diquark strings with gluon links + multiple low-pT exchange	?

Conclusions

The first question you should ask yourself : what do I want to do with my event generator?

- In pp at sqrt(s)=115 GeV, do you need all theory development needed for tevatron and LHC?

- If your goal is to study pA and AA : do you gain to have one single event generator (one physical framework and computing framework) for all systems and energies ?

- Do you gain to have one single event generator for all observables ?

- For quarkonia : at present moment there isn't a full event generator for pp, pA, AA with quarkonia implemented in a single framework (see Smbat and Cynthia's work)

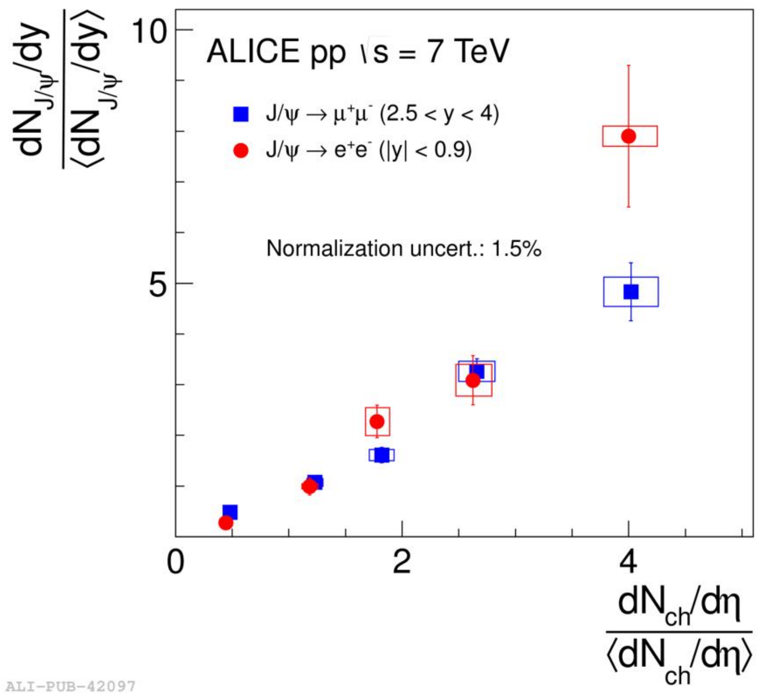
- The field is evolving quickly, improved MC will certainly be available when AFTER will be in operation, stay tuned

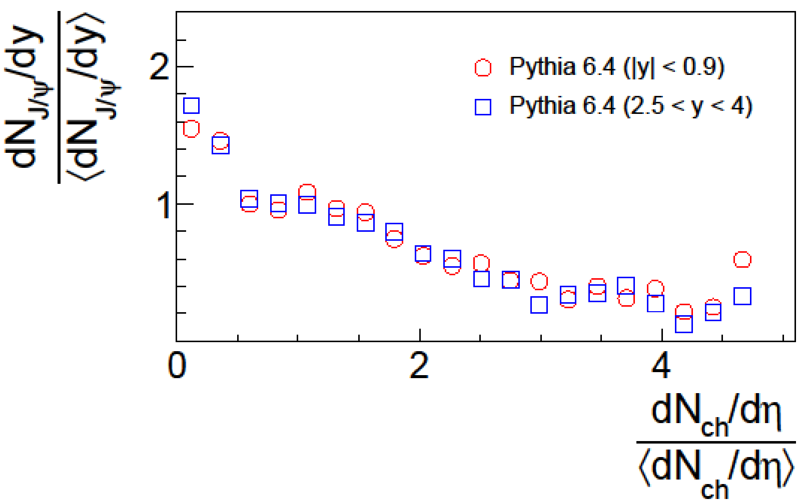
There isn't one easy answer, it depends on your preferences!

Backup

J/Psi vs. mult in pp @ 7 TeV

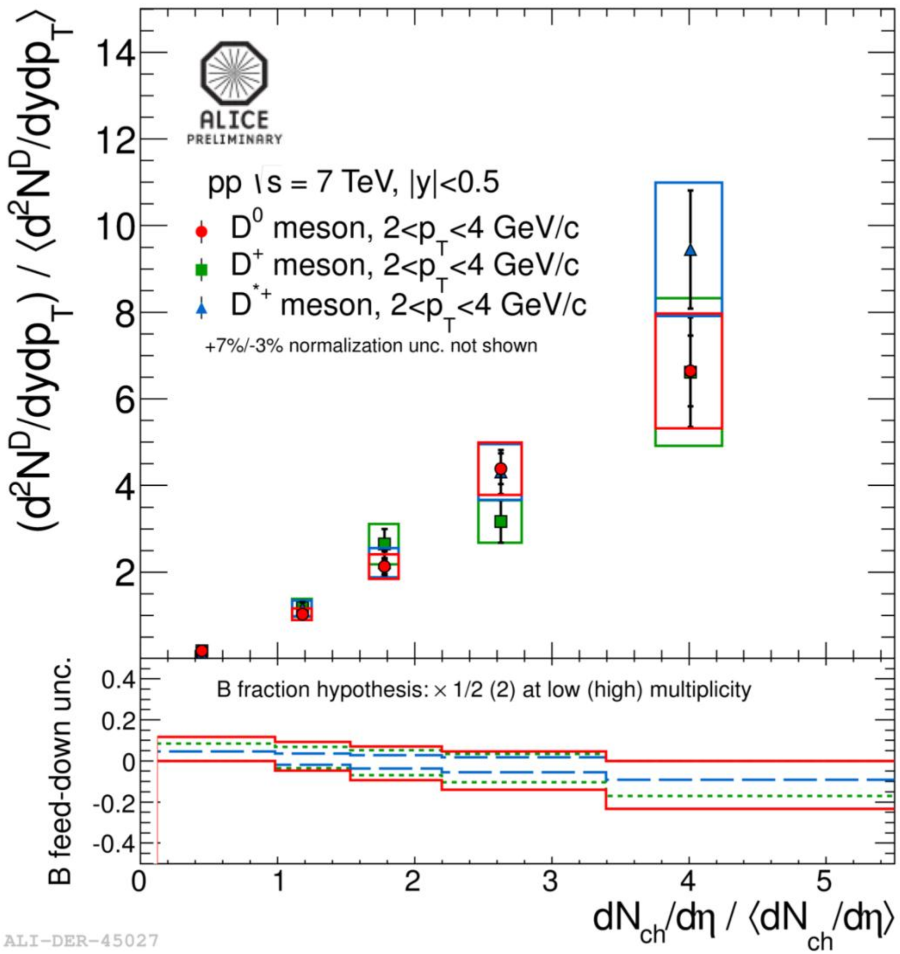
At LHC : looking at more exclusive observables in pp@ 7 Tev
Phys.Lett. B712, 165-175, 2012 / ArXiv:1202.2816

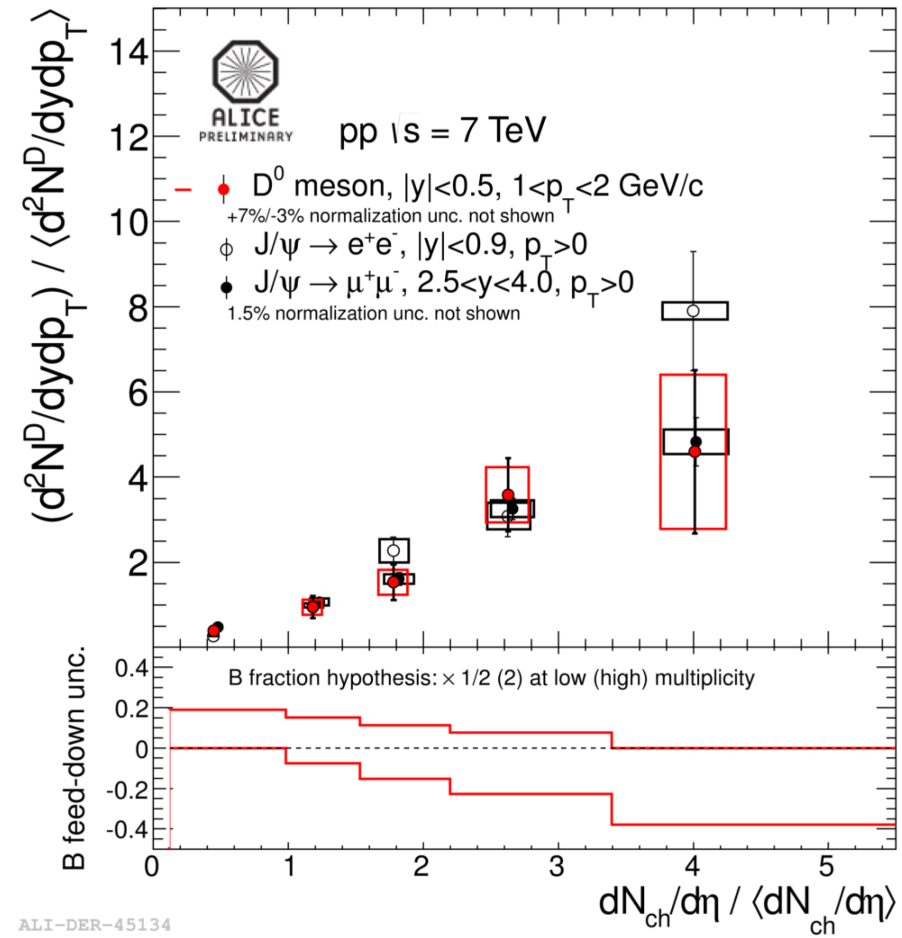




Will you look with AFTER at such observables, or quarkonia+correlations?

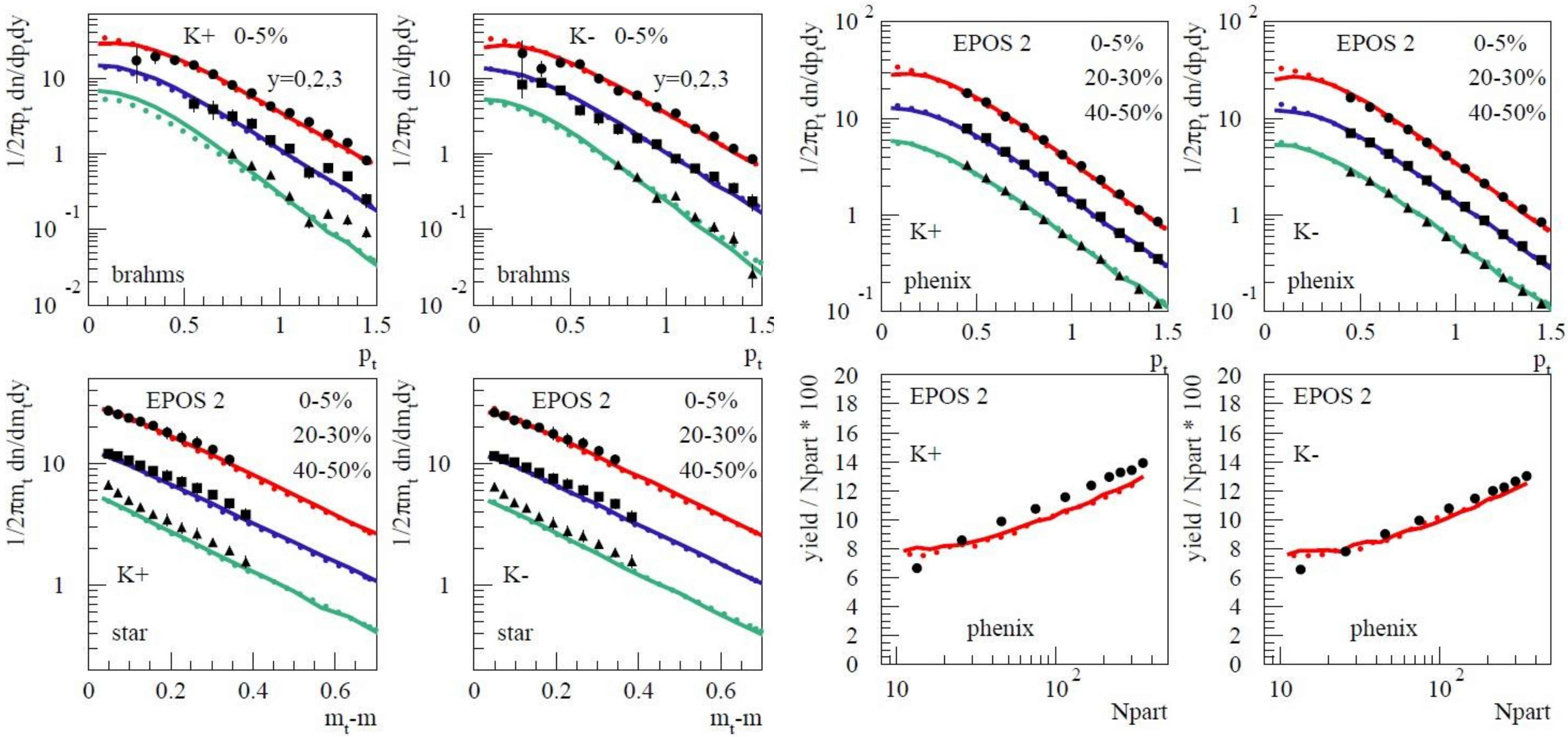
D vs. mult in pp @ 7 TeV





EPOS for heavy ion

Kaons at RHIC : AuAu, sqrt(s)=200 GeV



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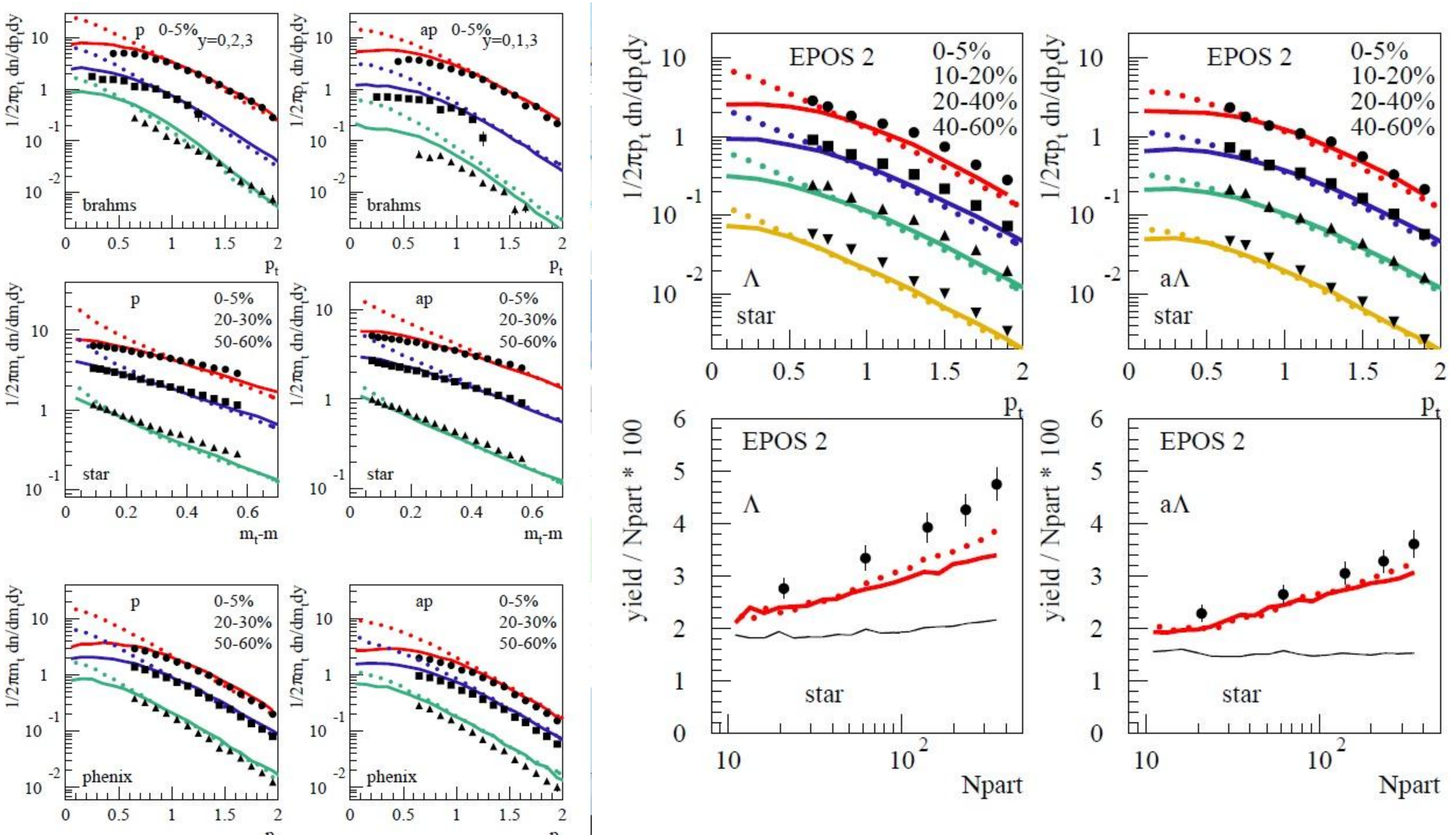
EPOS for heavy ion

Protons and lambda at RHIC : AuAu, sqrt(s)=200 GeV



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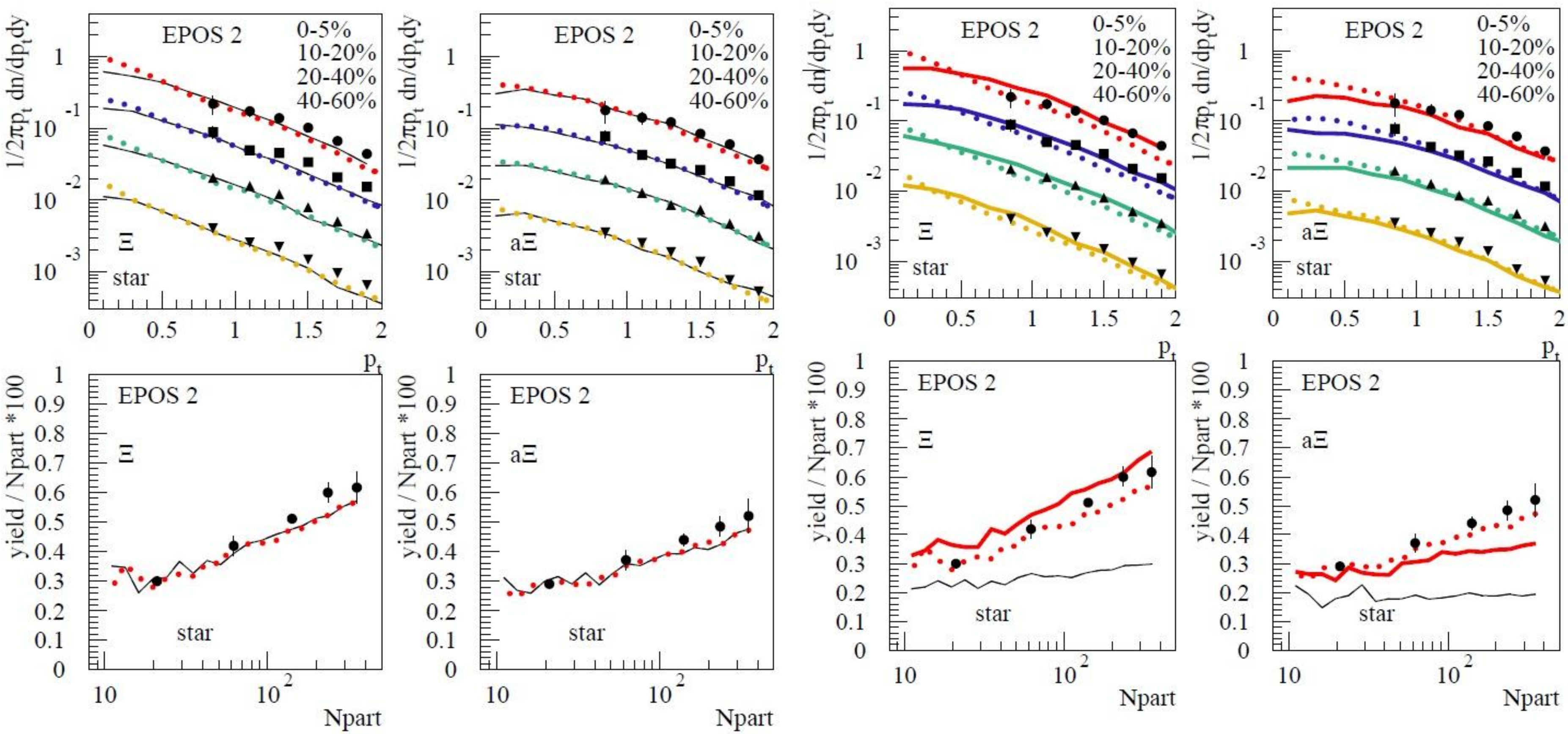
EPOS for heavy ion

Xi and Omega at RHIC : AuAu, sqrt(s)=200 GeV



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Many other variables and energies available in literature